

April 30, 1940.

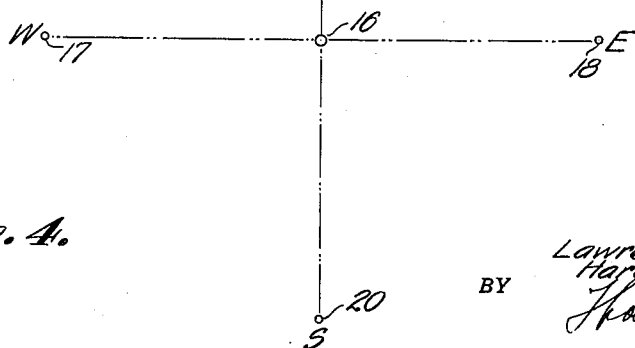
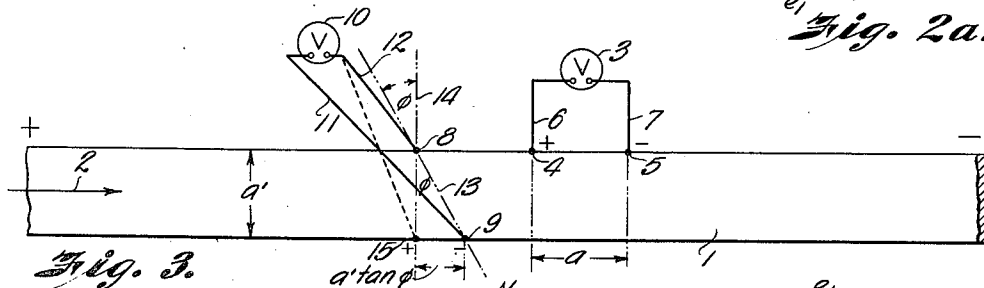
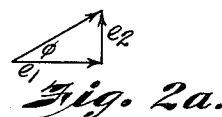
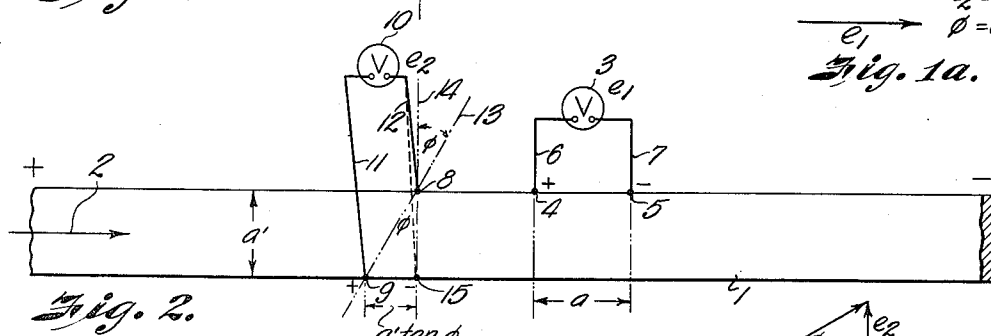
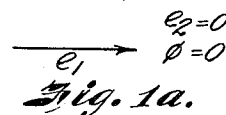
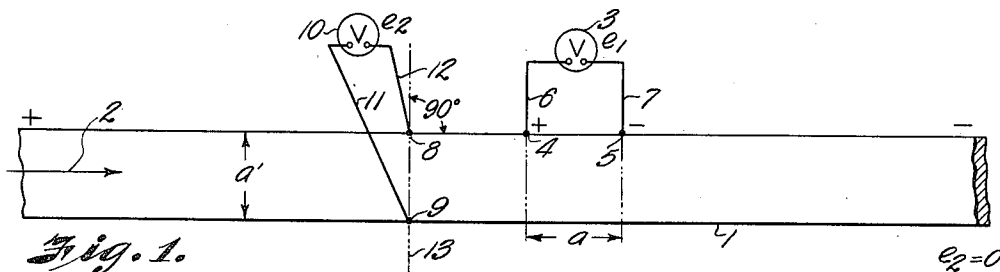
L. F. ATHY ET AL

2,199,367

METHOD OF LOGGING BORE HOLES

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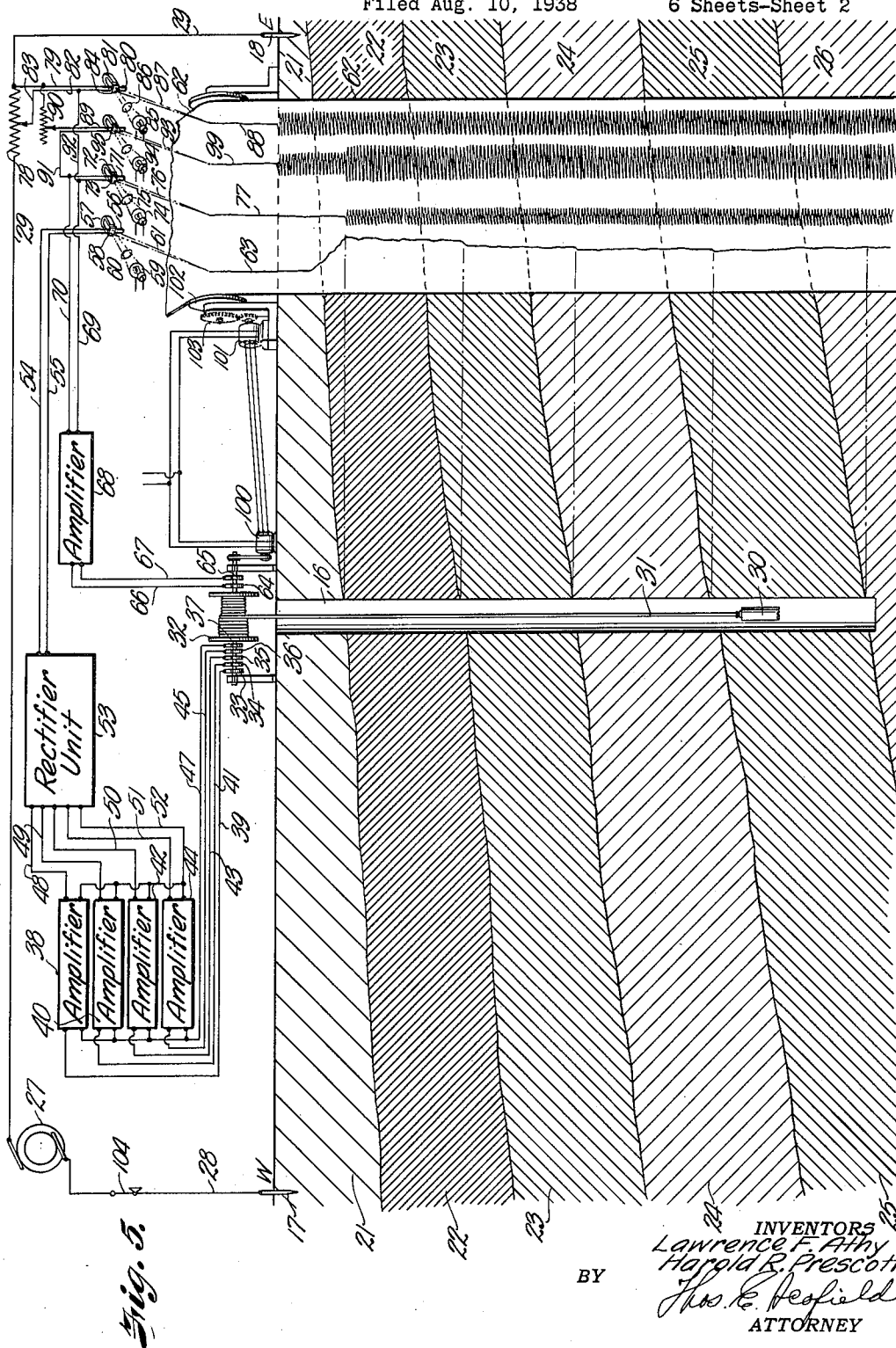
6 Sheets-Sheet 1



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6 Sheets-Sheet 2



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METHOD OF LOGGING BORE HOLES

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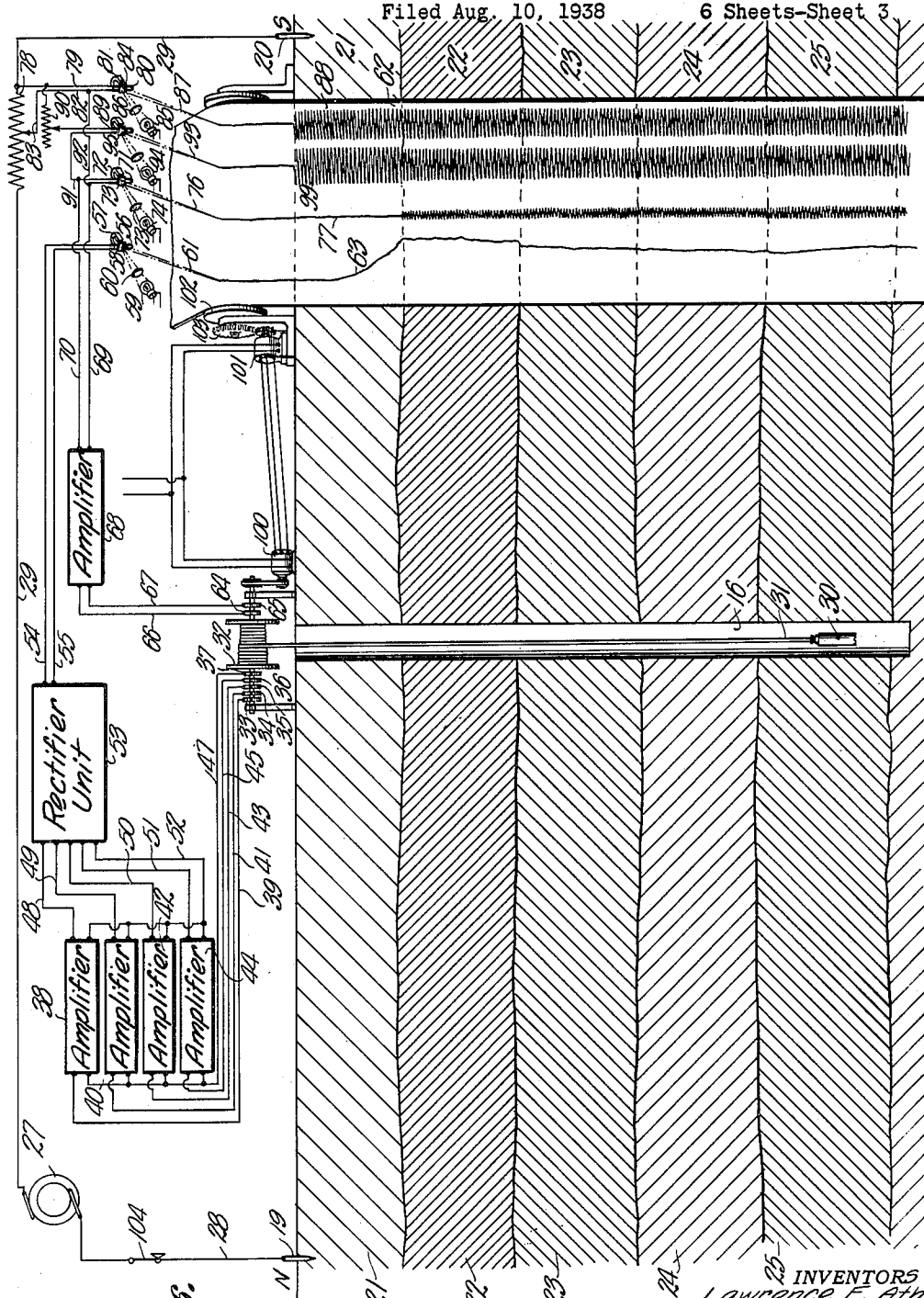


Fig. 6.

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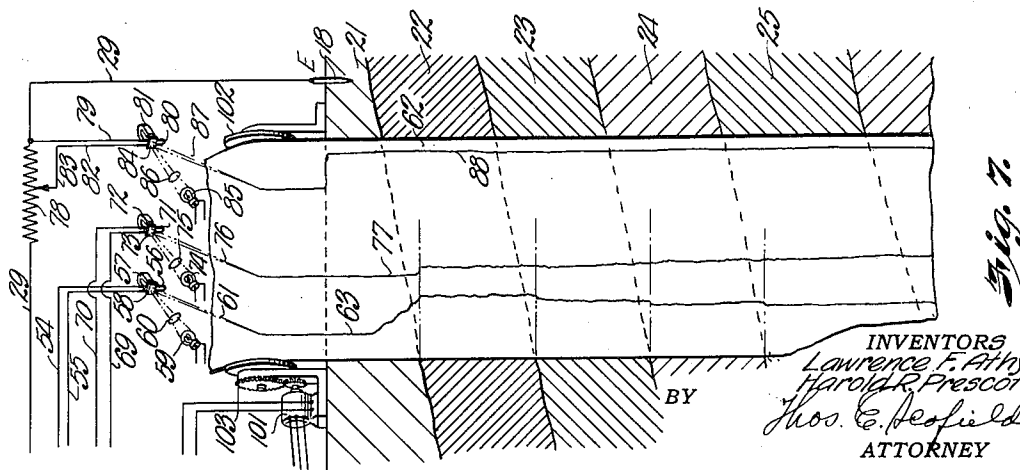
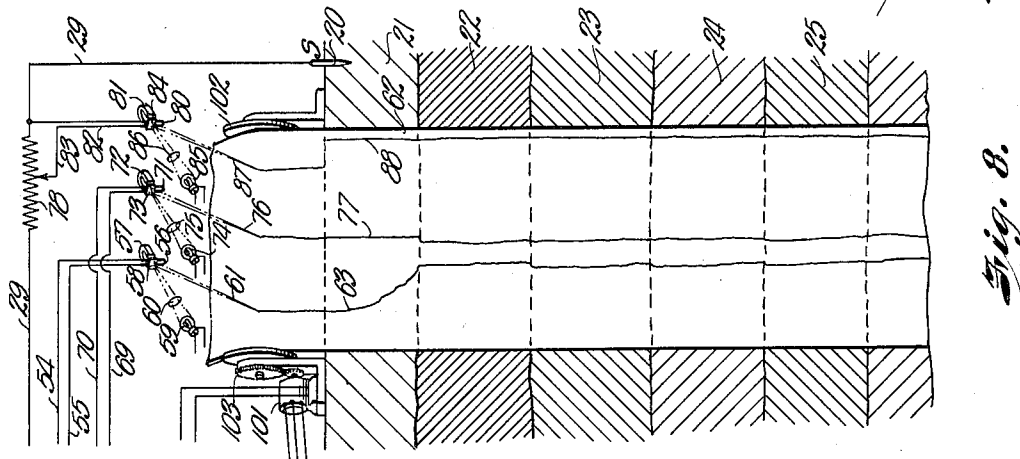
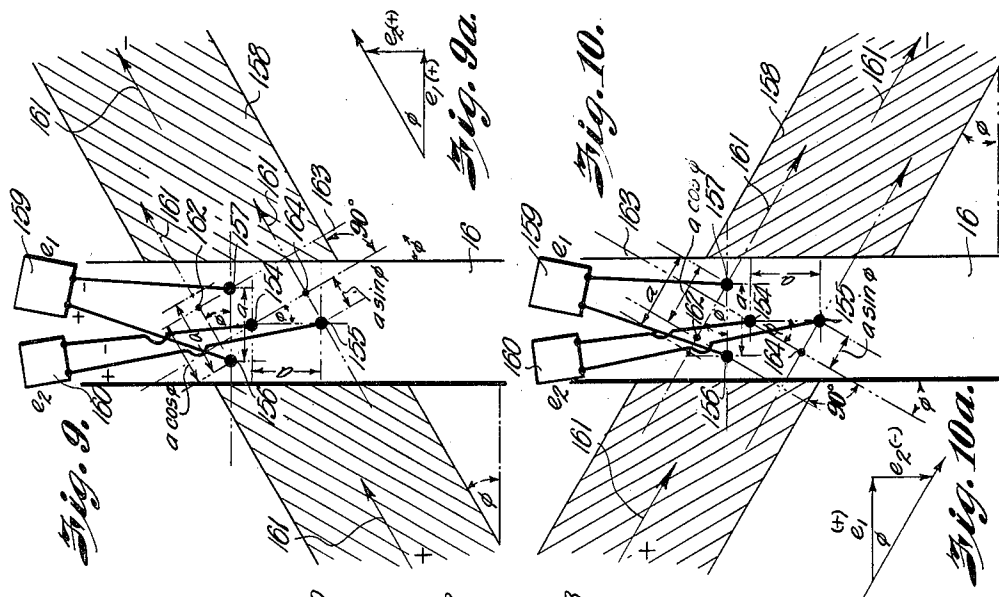
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METHOD OF LOGGING BORE HOLES

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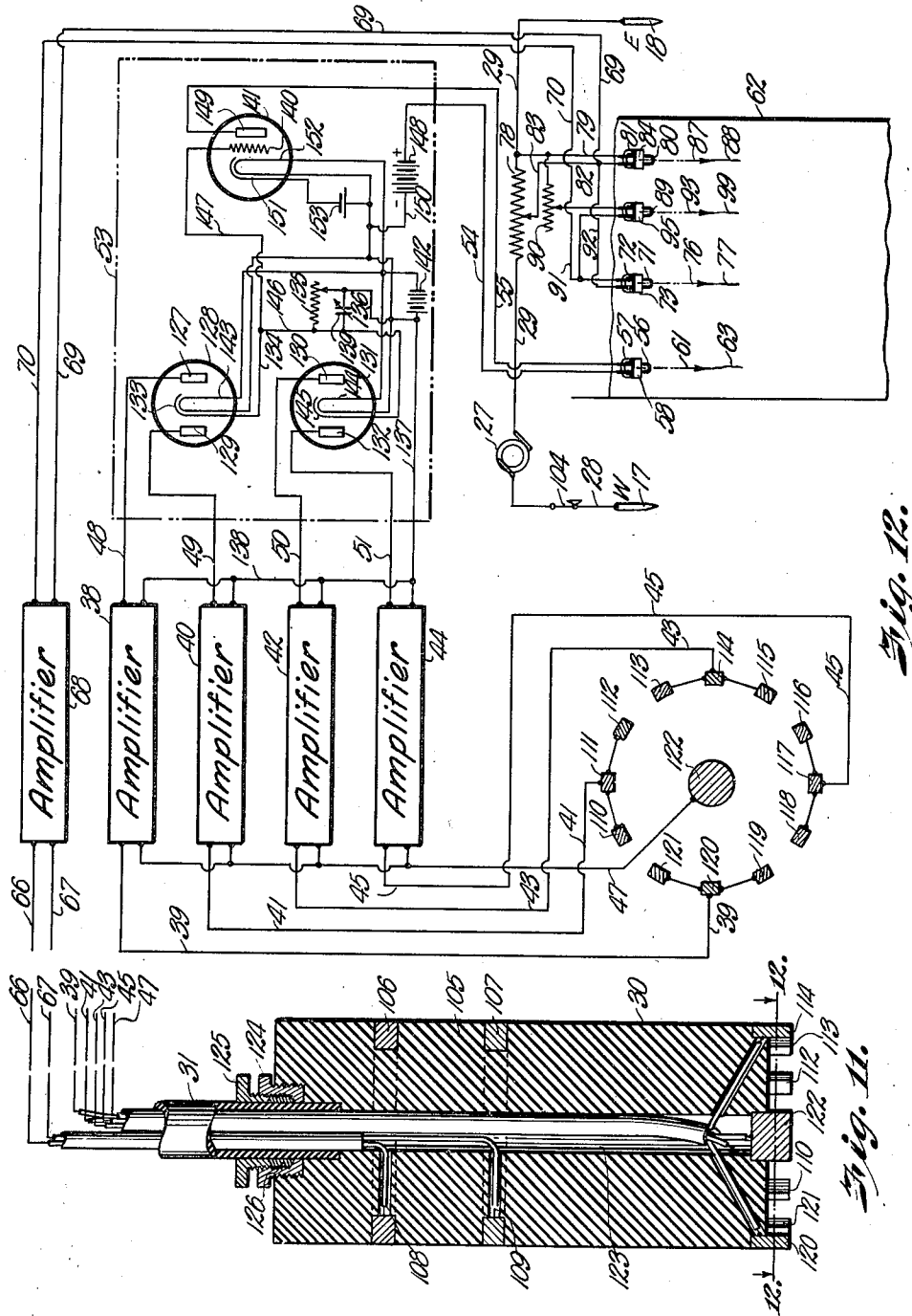


Fig. 12.

Fig. 11.

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METHOD OF LOGGING BORE HOLES

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6 Sheets-Sheet 6

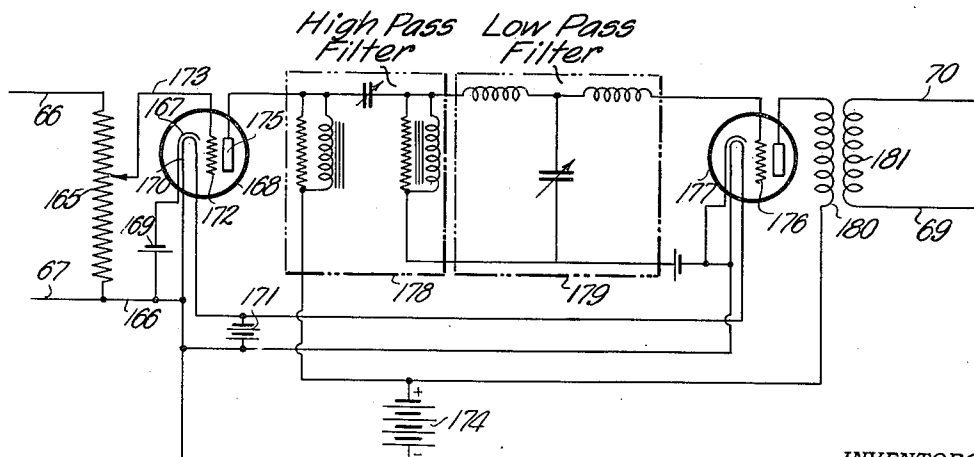
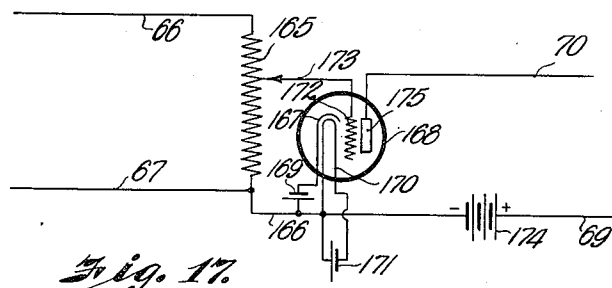
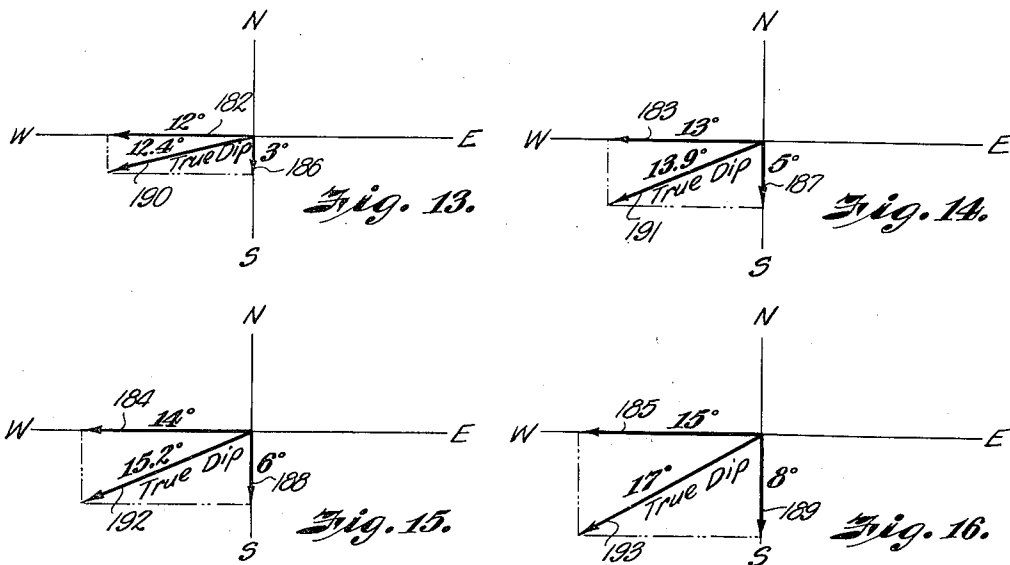


Fig. 18.

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UNITED STATES PATENT OFFICE

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METHOD OF LOGGING BORE HOLES

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Application August 10, 1938, Serial No. 224,105

8 Claims. (Cl. 175—182)

Our invention relates to a method of logging bore holes drilled into the earth and more particularly to a method whereby the amount and direction of dip of the geological formations penetrated is recorded, rather than their depth as has been the practice in logging methods of the prior art.

In exploration for oil, gas, and other valuable mineral deposits, after a hole is drilled into the earth, it is customary to employ various types of well logging methods to obtain accurate information of the character of the geological formations penetrated. This information can be plotted in the form of a log which can be compared with the logs of other bore holes and correlated to obtain a comprehensive picture of the underlying formations.

Since oil or gas occurs on a crest of an anticlinal fold or on the updip portion of a structure, if we can ascertain the amount and direction of the dip of geological formations, we may determine the updip direction from a dry hole drilled on a flank of a structure and thus be enabled intelligently to locate subsequent test wells.

One object of our invention is to provide a novel method of determining the dip or slope of rock layers through which a bore hole has been drilled.

Another object of our invention is to provide a novel method of determining structure by ascertaining the dip or the slope of the rock layers at several holes drilled in an area and plotting such dips to obtain a structure map.

Another object of our invention is to provide a method of bore hole logging in which the amount and direction of the dip of geological formations penetrated is recorded.

Other and further objects of our invention will appear from the following description.

In the accompanying drawings which form part of the instant specification and are to be read in conjunction therewith and in which like reference numerals are used to indicate like parts in the various views;

Figure 1 is a simplified diagrammatic view, used in connection with the explanation of the manner in which magnitude and direction of dip of geological strata pierced by a bore hole may be measured, in the case of a horizontal bed.

Figure 1a is a vector diagram of the voltage relationships along and across a horizontal bed.

Figure 2 is a simplified diagrammatic view used in connection with the explanation of the manner in which magnitude and direction of dip of geological strata pierced by a bore hole may be measured, in the case of a bed sloping upwardly to the right.

Figure 2a is a vector diagram of the voltages along and across the bed shown in Figure 2.

Figure 3 is a simplified diagrammatic view used in connection with the explanation of the manner

in which magnitude and direction of dip of geological strata pierced by a bore hole may be measured, in the case of a bed sloping downwardly to the right.

Figure 3a is a vector diagram of the voltage relationships along and across the bed shown in Figure 3.

Figure 4 is a plan view of the surface of the earth showing the arrangement of electrodes about the bore hole which pierces the geological strata.

Figure 5 is a diagrammatic view of an east-west cross section of a bore hole showing strata pierced thereby, the recording apparatus and a record strip obtained using alternating current.

Figure 6 is a diagrammatic view of a north-south cross section of a bore hole showing strata pierced thereby, the recording apparatus and a record strip obtained using alternating current.

Figure 7 is a diagrammatic view of a portion of the recording apparatus, a section of the geological strata across an east-west line and a record strip made using direct current.

Figure 8 is a diagrammatic view of a portion of the recording apparatus, a section of the geological strata across a north-south line and a record strip made using direct current.

Figure 9 is a detailed view of a particular geological strata showing the manner in which the potential of the electrodes in the bore hole may be used to indicate the dip of the bed.

Figure 9a is a vector diagram of the voltages across respective electrodes in Figure 9.

Figure 10 is another detailed view of a particular geological strata showing the manner in which the potential of the electrodes in the bore hole may be used to indicate the magnitude and direction of the dip of the strata.

Figure 10a is an electrode diagram of the potentials across the electrodes in Figure 10.

Figure 11 is a sectional view of our bore hole electrode assembly.

Figure 12 is a diagrammatic view showing a section of the electrodes assembly taken along the line 12—12 of Figure 11, connected to the amplifiers, the rectifier unit and the recording unit.

Figure 13 is a dip diagram obtained by the method of our invention.

Figure 14 is another dip diagram.

Figure 15 is another dip diagram.

Figure 16 is a further dip diagram.

Figure 17 is a diagrammatic view of the amplifier for the bore hole electrodes for use with direct current or with interrupted direct current at the surface electrodes.

Figure 18 is a diagrammatic view of an amplifier for the bore hole electrodes for use with alternating current at the surface electrodes.

Referring now to the drawings, Figure 1 shows an electrical conductor 1 of homogeneous material

which carries a current in a lateral direction indicated by the arrow 2. The voltmeter 3 indicates a voltage drop along the conductor between points 4 and 5 separated by a linear distance a , the voltmeter being connected to points 4 and 5 by conductors 6 and 7.

It will be obvious to those skilled in the art that the magnitude of the voltage e_1 recorded by the voltmeter 3 will be an index of the quantity of current flowing through the conductor 1 and the direction of current flow will be indicated by the direction of the indication of the voltage e_1 . In other words, if the voltmeter 3 indicates that the conductor 6 is positive with respect to conductor 7, then obviously current will be flowing as indicated by the arrow 2 in Figure 1.

Along a line 13, at right angles to a line connecting points 4 and 5, across points 8 and 9, we connect a voltmeter 10 by means of conductors 11 and 12. It will be obvious that, since points 8 and 9 are directly above one another and the conductor 1 is horizontal, there will be no voltage drop between these points since it is assumed that the material 1 is homogeneous.

Referring now to Figure 1a, it will be observed that the inclination of the direction of a line drawn through points 4 and 5, with respect to a line normal to a line drawn through points 8 and 9, will be indicated by the angle whose tangent is

$$\frac{e_2}{e_1}$$

In this case, since e_2 is 0, the tangent will be 0 and the angle ϕ will be 0.

Referring now to Figure 2 (in which reference numerals similar to those used in Figure 1 are employed) it will be observed that point 8 is now further to the right than point 9. In other words, the line 13 drawn through points 8 and 9 forms an angle ϕ with a line 14 normal to the direction of the current, along which no potential difference exists. The potential difference between points 8 and 9 is the same as that which would exist between points 9 and 15, because the line 14 is that of 0 potential change. The actual distance between points 9 and 15 = $a \tan \phi$. The potential drop between points 9 and 15 varies as a function of $a \tan \phi$. In other words $e_2 = Ka' \tan \phi$, where K is a constant depending upon the current and the impedance of the conductor. Similarly

$$(e_1) = Ka \tan \phi = \frac{e_2}{Ka} = \frac{e_2}{e_1}$$

The above relations are shown in Figure 2a by a vector diagram in which

$$\tan \phi = \frac{e_2}{e_1}$$

The polarity of point 9 in Figure 2 with reference to point 15 (and hence point 8) will indicate the direction. Furthermore, since

$$e_2 = Ka' \tan \phi$$

and $e_1 = Ka \tan \phi$ is independent of Ka since $\tan \phi$ may be represented as the ratio

$$\frac{e_2}{e_1}$$

It will be obvious from the foregoing, to those skilled in the art, that the results obtained will be independent of either K or a . In other words, the determination of the angle ϕ by means of its tangent is independent of the quantity of current used, the receptivity of the conductor in-

involved or of the separation between points 4 and 5 (a).

In order to be able to determine the angle ϕ , it is required only that the conductor be homogeneous in the region of points 4, 5, 8 and 9 and that a be equal to a' or, if different values are employed for a and a' , that the necessary computation steps are taken to reduce voltages e_2 and e_1 to values corresponding to equal values of a and a' , (it being understood that a' is the vertical separation between points 8 and 9, as indicated in the figures).

Figure 3 is similar to Figure 2 but point 8 is connected at a point farther to the left than point 9. In other words, ϕ is in a different direction to the horizontal than ϕ in Figure 2. This is indicated by the fact that, though the magnitudes of e_1 and e_2 are the same in Figure 3 as in Figure 2, the polarity is reversed.

Figure 3a is a diagrammatic view similar to Figure 2a, showing the vector diagram of the potentials.

Figure 4 is a plan view looking down at the earth's surface upon a bore hole 16. The current stake 17 is due west of the bore hole 16. The current stake 18 is due east of the bore hole 16. The current stake 19 is due north of the bore hole 16, and the current stake 20 is due south of the bore hole 16. It will be noted that the electrodes 17, 18, 19, and 20 are placed at equal distances from the bore hole 16 in Figure 4. This is not absolutely necessary. The distances between the current stakes and the bore hole should be such that a sufficient current will penetrate to the deepest geological strata to be investigated. It is also desirable to make the distances between the bore hole and the current stakes of a rather large order in order that the current in the geological strata pierced by the bore hole will flow along the beds with substantially no curvature in the region of the bore hole. In order to accomplish this result, we have found that the distance between an electrode and the bore hole should be from one to one and a half times the depth of the deepest geological strata to be investigated.

Referring now to Figure 5, which is a section through the bore hole 16 taken on an east-west line, it will be noted that the bore hole pierces a plurality of layers 21, 22, 23, 24, 25, and 26. The layer 21 is the surface or weathered layer. The bed 22 is a high conductivity bed. The bed 23 is a medium conductivity bed. The bed 24 is a low conductivity bed, while the bed 25 is another medium conductivity bed. The east and west bore hole electrodes are connected across the output of an alternator 27 by means of conductors 28 and 29. It is to be understood that observations are made across one plane, that is either in a north-south, or east-west direction, at one time. The electrode system 30, shown in greater detail in Figures 11 and 12, is lowered into the bore hole by means of a cable 31, normally wound upon a reel 32. The cable 31 is provided with conductors. These conductors are connected to slip rings 33, 34, 35, 36 and 37. Slip ring 33 is connected to amplifier 38 by conductor 39. Slip ring 34 is connected to amplifier 40 by conductor 41. Slip ring 35 is connected to amplifier 42 by conductor 43. Slip ring 36 is connected to amplifier 44 by conductor 45. The return circuits for the amplifiers 38, 40, 42, and 44 is by way of conductor 47 to slip ring 37. The output of the amplifiers is led by conductors 48, 49, 50, 51, and 52 to a rectifier unit 53. The out-

put of the rectifier unit 53 is impressed by conductors 54 and 55 upon oscillograph element 56 suspended in the field of a magnet 57. The oscillograph element 56 carries a mirror upon which light from an incandescent lamp 59 is focused by lens 60 for reflection along path 61 upon the sensitized record strip 62 to form a trace 63. Two of the conductors are connected to slip rings 64 and 65, which are, in turn, connected by conductors 66 and 67 to the input of an amplifier 68. The output of amplifier 68 is impressed by conductors 69 and 70 upon an oscillograph element 71 positioned in the field of a magnet 72. The oscillograph element 71 carries a mirror 73 upon which light from an incandescent lamp 74 is focused by a lens 75 for reflection along path 76 upon the record strip 62 to form oscillograph trace 77. A resistance 78 is placed in the conductor 29 across the output of the alternator 27. One side of the resistance 78 is connected by conductor 79 to an oscillograph element 80, positioned in the field of a magnet 81. The other side of the oscillograph element 80 is connected by conductor 82 and adjustable arm 83 to a point upon resistance 78, since the arrangement described will cause oscillograph element 80 to measure the IR drop between the point of connection of conductor 79 and the point of contact of adjustable arm 83 of resistance 78. Since the resistance at any given time will be fixed, the IR drop will vary as a function of the current and hence oscillograph element 80 will measure the current flowing through conductor 29. The oscillograph element 80 carries a mirror 84 upon which light from an incandescent lamp 85 is focused by lens 86 for reflection along path 87 upon the record strip 62 to form oscillograph trace 88.

One side of oscillograph element 89 is connected through variable resistance 90 to conductor 79. The other side of oscillograph element 89 is connected by conductor 91 to one side of the output of amplifier 68 at conductor 70. A conductor 92 connects the other side of the output of amplifier 68, that is conductor 69, to conductor 82. In other words, oscillograph element 89 is interconnected with oscillograph elements 71 and 80 to record the instantaneous summation of the voltages influencing these oscillograph elements. In this manner, the relative phase of the voltages recorded by oscillograph element 71 with respect to the voltages recorded by oscillograph element 80 will be recorded by the trace of oscillograph element 89. This trace is formed by the reflection along path 93 of light from incandescent lamp 94 by mirror 95 to form trace 99. When the amplitude of trace 99 is high, the voltages impressed upon oscillograph elements 71 and 80 are in phase. When the amplitude of the trace 99 is small, the voltages impressed upon oscillograph elements 71 and 80 are out of phase. The sensitivity of the oscillograph element 89 is arranged to be much greater than the sensitivity of oscillograph element 71 or oscillograph element 80 and the resistance 90 is used in series with oscillograph element 89 to minimize the current flowing through this element. This permits the oscillograph element 89 to record appreciable amplitudes with a current which will give substantially no deflection to oscillograph elements 71 and 80. It will be seen that our arrangement permits the oscillograph element 71 to record substantially nothing but the output of the amplifier 68. It permits oscillograph element 80 to record substantially nothing but the

output from the resistance 78 (the current output of the alternator). At the same time, oscillograph element 89 will record the summation of the outputs impressed upon oscillograph elements 71 and 80.

The initial connections are made so that traces 77 and 88 are in phase when the beds are higher under electrode 18, the east electrode, when surveying in an easterly-westerly line. Similarly, the initial connections are such that the traces 77 and 88 are in phase when the beds are higher under the south electrode 20.

Oscillograph trace 99 is normally arranged to give the same amplitude as oscillograph trace 88 by adjustment of the resistance 90, when the amplitude of trace 77 (e_2) is 0. When trace 77 (e_2) shows that potential exists across the vertically spaced electrodes of the receptor 30, the oscillograph 99 will increase if traces 77 and 88 are in phase. Likewise, the oscillograph trace 99 will decrease if traces 77 and 88 are out of phase. The oscillograph element 89 and the oscillograph trace 99 are needed only where an alternator is used as the current source. With direct current, the oscillograph 89 may be disconnected.

The connections to the oscillographs are shown on a larger scale in Figure 12 in which like reference numerals are used to indicate like parts.

The reel 32 is rotated to move electrode assembly 30 into and out of the bore hole by means of a motor 100. The motor 100 is a synchronous motor and connected in parallel with motor 101 which drives the roll 102 which moves the record sheet 62 through reduction gearing 103. By this arrangement, the record sheet will move as a function of the motion of the electrode assembly so that the record sheet will furnish a graph from which the inclination and direction of dip of the beds may be read at their respective depths. The key 104 is adapted to complete the circuit to the electrodes 17 and 18 from the alternator 27. If desired, the key may be momentarily closed in order to give transient impulses.

Referring now to Figure 11 in which there is shown an enlarged view of electrodes assembly 30, the body member 105 is made out of any suitable insulating material and contains adjacent its upper portion a conducting ring 106 separated a predetermined distance from a conducting ring 107. Connected to conductor ring 106 is conductor 108 of the cable 31. Connected to conductor ring 107 is the conductor 109 of the cable 31. Conductors 108 and 109 are connected to slip rings 64 and 65 which are connected by conductors 66 and 67 to the amplifier 68. The potential difference existing between rings 106 and 107 is voltage e_2 , that is the voltage drop between two vertically separated points.

The measuring electrode arrangement to obtain e_1 is more complicated due to the fact that it must record a voltage drop between two horizontal points irrespective of orientation. In order to accomplish this, we provide adjacent the lower portions of body 105 a plurality of conducting points 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, and 121, disposed about a central conducting element 122. Electrode points 119, 120, and 121 are connected as a group to conductor 39 leading to amplifier 38. Conducting points 110, 111, and 112 are connected as a group to conductor 41 leading to amplifier 40. Conducting points 113, 114, and 115 are connected as a group to conductor 43 leading to amplifier 42. Electrode points 116, 117 and 118 are connected

as a group to conductor 45 leading to amplifier 44. The center electrode 122 is connected by conductor 47 to one side of all four amplifiers 38, 40, 42, and 44, as can readily be seen by reference to Figure 12. The conductors are housed in cable 31 which leads into a bore 123 formed in the body 105 of the electrodes assembly. The cable passes out of the bore 123 through a stuffing box assembly as can readily be seen by reference to Figure 11. The lower member 124 of the stuffing box assembly is threaded or otherwise secured to the top of the body member 105. The upper member of the stuffing box 125 is adapted to squeeze packing 126 against the outside of cable 31 tightly to secure the cable to the member 124 which in turn supports the body member 105 and the electrodes assembly. The central electrode 122 closes lower end of bore 123 and prevents the ingress of bore hole fluid into the bore, which might result in the short circuiting of the electrodes. The output of amplifier 38 is impressed through conductor 48 upon the anode 127 of duo-diode vacuum tube 128. The output of amplifier 40 is led by conductor 49 to anode 129 of duo-diode vacuum tube 128 of the rectifier unit 53. The output of amplifier 42 is conducted by conductor 50 to the anode 130 of the duo-diode vacuum tube 131 of the rectifier 53. Conductor 51 is adapted to impress the output of amplifier 44 upon the anode 132 of the duo-diode vacuum tube 131 of the rectifier 53. Each anode will pass current when it becomes positive and will permit current to flow to its respective cathode. For example, when anode 127 of tube 128 becomes positive with respect to the cathode 133, current will flow from the anode 127 to the cathode 133 through conductor 134 through resistance 135 through conductor 136 through conductor 137 which is the common cathode return to all amplifiers. It will be noted that the other side of each amplifier is connected to conductor 138 which is connected to conductor 137.

In parallel with the resistance 135 we place a variable condenser 139 which is adjusted to filter out individual pulsations when alternating current is employed. The capacity of condenser 139 and the resistance 135 are adjusted to give a time constant sufficiently large that individual pulsations of alternating current will be smoothed out, but sufficiently small that variations in amplitude of potential across the electrodes, a very short time later, will be indicated by a similar variation of potential upon the grid 140 of the vacuum tube 141.

It will be obvious from a view of Figure 12, that a similar flow of current through resistance 135 and common return conductor 137 will take place when any of the anodes 127, 129, 130, or 132 becomes positive with respect to their respective cathodes. Battery 142 furnishes energy for filament 144 which heats the cathode 145 of tube 131. Cathodes 133 and 145 are interconnected by a conductor 146 to which grid 140 is connected by conductor 147. It will be obvious that the potential impressed upon grid 140 will be the integral of the rectified potentials from all four amplifiers. A B battery 148 is connected through the plate 149 of tube 141 through oscillograph element 56. The other side of B battery 148 is connected by conductor 150 to the cathode 151 of tube 141. The filament heater 152 for the cathode is furnished energy from the battery 142. A C battery 153 furnishes bias for the cathode 151.

From the foregoing, it will be obvious that the oscillograph element 56 will move as a function of the rectified potential from all four ampli-

fiers 38, 40, 42, and 44, in view of the manner in which the electrodes 110, 112, 113, 114, 115, 116, 117, 118, 119, 120, and 121 are arranged around the central electrode 122, as shown in Figure 12. The potential impressed upon the grid 140 of the tube 141 by conductor 147 will be substantially independent of the orientation of the horizontal electrode system. It will be further obvious that the oscillograph 56 is controlled by the potential between the central electrode 122 and the peripheral electrodes. This potential is potential e_1 . It will be clear to those skilled in the art that the horizontal electrode system may be made nondirectional to a greater extent by the use of more electrodes disposed about the peripheral, and more amplifiers on the corresponding rectifier tubes.

The output of amplifier 68 will vary as a function of potential e_2 . This is impressed by conductors 69 and 70 upon oscillograph element 71 as hereinabove described. The electrode spacing may be any convenient spacing which is much less than the thickness of the geological strata to be investigated. Since electrode spacing is considerably less than the thickness of the strata, the ratio of the two potentials will represent values within a single stratum and will therefore represent dip.

The electrode system with its amplifiers may be pre-calibrated by calculation. We prefer to suspend the electrode system in a fluid between a pair of immersed conducting plates. We then pass current between the two conducting plates and place the electrode system at known angles with reference to the conducting plates, and adjust amplifier gains until

$$\frac{e_2}{e_1}$$

is equal to the tangents of the various known angles.

Referring now to Figure 9, the points 154 and 155 represent the vertical electrode system. Points 156 and 157 represent the horizontal electrode system. It will be noted that the points are disposed within the bore hole 16. Before immersion, the bore hole is filled with a normal drilling fluid. The stratum 158 is a buried stratum being investigated. Electrode points 156 and 157 are connected to the means 159 for measuring and indicating magnitude and polarity of the voltage e_1 obtained across conductors 156 and 157. Electrode points 154 and 155 are connected to a means 160 for measuring and indicating the magnitude and polarity of the voltage e_2 obtained across conductors 154 and 155. These electrode points or conductors are more or less vertically spaced, due to the fact that the electrode system is suspended. Conductors 156 and 157 are in the same general horizontal plane since they are placed at right angles to the axis of the electrode system assembly which is suspended by means of a cable.

The arrows 161 indicate the instantaneous direction of the current flow through the stratum 158. The current through the bore hole will parallel the geological strata as will readily be seen by reference to Figure 9. It will be obvious that the current will thus follow the strata if we consider the stratum 158, one of good conductivity, surrounded by beds of poor conductivity. The current will show a marked tendency to follow the good conductor laterally along the stratum and parallel to it.

The voltage e_1 between points 156 and 157 will be the same as that between point 156 and point

162. The linear distance between points 156 and 162 is $a \cos \phi$, where ϕ is the angle of dip and a is the linear spacing between electrodes 156 and 157. The voltage e_1 therefore, is proportional to the distance $a \cos \phi$. In other words,

$$e_1 = Ka \cos \phi.$$

Similarly, the voltage e_2 is measured by the measuring and recording means 160 which is connected to the vertical electrode points 155 and 154. The line 163 is one of equal potential, because it is drawn at right angles to the strata 158. By this is meant that an electrode positioned on line 163 will have the same potential as any other electrode positioned upon said line 163, though vertically displaced therefrom. From this, it follows that electrode 154 will have the same potential with reference to electrode 155 as point 164 has with reference to point 155. The voltage e_2 therefore is proportional to $a \sin \phi$, where a is the vertical interelectrode space and ϕ is the dip of the stratum 158. This may be expressed $e_2 = Ka \sin \phi$.

$$\tan \phi = \frac{a \cos \phi}{a \sin \phi}$$

$$\tan \phi = \frac{Ka \cos \phi}{Ka \sin \phi} = \frac{e_2}{e_1}$$

This is shown graphically in Figure 9a where the length of the arrows e_1 and e_2 indicate the respective magnitudes of the potential differences and the directions of the arrows indicate the polarity of the potentials.

Figure 10 is similar in all respects to Figure 9 except that the stratum 158 dips in the opposite direction, though a like amount. The magnitude and polarity of e_1 will be the same as before. The magnitude of e_2 will be the same as before. Its polarity, however, is changed. This is readily discernible by reference to Figure 10a which is similar to Figure 9a but in which e_2 is plotted in the opposite direction, due to the fact that its polarity is the opposite.

When direct current or intermittent direct current is employed at the electrodes 17, 18, 19, and 20, all of the amplifiers employed in the system are like that shown in Figure 17. The conductors 66 and 67 connected to bore hole electrodes through the cable are connected across resistance 165, one end of which is connected by conductor 166 to the cathode 167 of a vacuum tube 168 through a cathode biasing C battery 169. A cathode heater filament 170 is furnished energy from an A battery 171, the grid 172 being connected by arm 173 to a point upon the resistance 165. The positive side of B battery 174 is connected to the plate 175 of tube 168 through an oscillograph element.

When alternating current or transient impulses are used, the amplifier shown in Figure 18 is employed throughout. Resistance 165 is connected across conductors 66 and 67, leading to the bore hole electrodes through the slip ring arrangement to the cable. The output of the first vacuum tube 168 is impressed upon the grid 176 of the output tube 177 through a high pass filter 178 and a low pass filter 179. The high pass filter rejects undesirable frequencies below that of the source frequency. The low pass filter 179 rejects undesirable high frequencies above that of the source frequency. The primary 180 of a transformer is placed in the plate circuit of the output tube 177. The secondary 181 of the output transformer is connected across the oscillograph element by conductors 69 and 70.

Referring now to Figure 7, there is shown a record strip 62 made with direct current. The oscillograph element 56 records potential e_1 . The value of e_1 for the various beds is shown by trace 63. Oscillograph element 71 gives the potential e_2 . The value of e_2 as the electrodes assembly 30 is lowered through the bore hole is given by trace 77. Oscillograph element 80 gives trace 88 which indicates the current in the surface electrodes 19. It will be observed that e_2 has the same direction of motion (polarity) as indicated by trace 77 as trace 88. This means that the bed is higher under electrode 18, the east electrode, than it is under the west electrode. That is, bed 22 is dipping downward toward the west by an angle whose tangent is

$$\frac{e_2}{e_1}$$

which, in the case illustrated, would be an angle whose tangent is .213, or an angle of 12 degrees. This is shown in Figure 13 where arrow 182 is drawn toward the west a length proportional to 12 degrees. Similarly, bed 23 is higher under electrode 18 and the value of

$$\frac{e_2}{e_1}$$

is .23. The angle whose tangent is .23 is 13 degrees. Arrow 183 in Figure 14 is a plot of this value. In the same manner, we obtain from record strip 62 of Figure 7 that the value of

$$\frac{e_2}{e_1}$$

for bed 24 is .25. The angle whose tangent is .25 is 14 degrees. Since the trace 88 is in the same direction as trace 77, bed 24 is higher under electrode 18. The vector 184 in Figure 15 is pointed from the bore hole westerly a value representing 14 degrees. From the record strip 62, the value of

$$\frac{e_2}{e_1}$$

for bed 25 is found to be .268. The angle whose tangent is .268 is 15 degrees. Trace 88 being in the same direction as trace 77, the bed is higher under electrode 18 and the vector 185 in Figure 16 indicates the east-west component of bed 25.

Referring now to Figure 8, the record strip 62 in this figure is taken on a north-south line. The value of e_1 is given by trace 63; the value of e_2 is given by trace 77; and the value and direction of the surface electrode current is recorded by trace 88. Examining the record strip in Figure 8, it will be observed that the trace 63 is in the opposite direction from trace 77. This means that the beds are lower under the south electrode 20 than under the north electrode 19. From the record strip, the value of

$$\frac{e_2}{e_1}$$

in the vicinity of bed 22 is .052. The angle whose tangent is .052 is 3 degrees. The vector 186 in Figure 13 is plotted a distance proportional to 3 degrees in a direction indicating that the beds are dipping from north to south. In the same manner, the value of

$$\frac{e_2}{e_1}$$

for bed 23 in Figure 8 is .087. The angle whose tangent is .087 is 5 degrees, the dip again being from north to south. The vector 187 in Figure 14 is plotted a distance

proportional to 5 degrees in a direction pointing from north to south. The value of

$$\frac{e_2}{e_1}$$

for bed 24 in Figure 8 is .105 or the tangent of 6 degrees. The vector 188 in Figure 15 flies south a length proportional to 6 degrees. Similarly, from the record strip, we obtain a value of 8 degrees for bed 25,

$$\frac{e_2}{e_1}$$

being .141. The vector 189 in Figure 16 flies south a distance proportional to 8 degrees.

Figure 13 shows the east-west component and the north-south component of the true dip in bed 22. The resultant vector 190 in Figure 13 indicates the extent and direction of the true dip of bed 22. In Figure 14, the resultant vector 191 indicates the true dip and direction of dip of bed 23. The resultant vector 192 in Figure 15 indicates the true dip of bed 24, both in direction and amount, while the resultant vector 193 of Figure 16 indicates the true dip both in direction and amount which exists in bed 24 in the region of bore hole 16. The same information as hereinabove described with respect to the use of direct currents is obtained with alternating currents.

Referring now to Figure 5, where the record strip 62 shows the traces obtained, trace 63 is proportional to the value of e_1 . Trace 77 is proportional to the value of e_2 . Trace 88 indicates the value of the alternating current passing through the surface electrodes 17 and 18, while trace 99, as described above, indicates whether the value of e_2 is in phase with the value of the surface electrode current. It will be seen by comparing trace 77 and trace 99 that, when trace 77 increases in amplitude, trace 99 also increases in amplitude, clearly showing that the current e_2 is in phase with the current passing through the surface electrodes. This indicates that the beds are higher under electrode 18. Since trace 63 is the rectified horizontal component e_1 it will be noted that trace 63 of the record strip in Figure 5 is substantially the same as trace 63 in the record strip shown in Figure 7. The value of e_2 is given by the amplitude of the trace 77 and substantially the same information is obtained from the record strip shown in Figure 5 as that shown in Figure 7 and the east-west electrodes and their directions are obtained and plotted as described above.

Referring now to Figure 6, which is similar to Figure 5, except that readings are being taken in a north-south direction, it will be seen by reference to the record strip 62 that, when the amplitude of trace 77 increases, the amplitude of trace 99 decreases. This indicates that e_2 is out of phase with the current passing through the surface electrodes 19 and 20. This indicates that, in a north-south direction, the beds are deeper under electrode 20, that is, the beds are dipping from north to south. The same information is obtained from the record strip 62 of Figure 6, which is obtained from the record strip 62 shown in Figure 8. Trace 63 being the rectified horizontal component, e_1 is the same as trace 63 of Figure 8. The amplitude of trace 77 indicates the value of e_2 .

In actual use, some general information of the direction of the dip will be known from geological information. This furnishes an addi-

tional check as to the direction of dip. Generally, this information is not necessary but, in the case of small dip angles, that is where the beds are nearly horizontal, it furnishes a check on the adjustment of the apparatus.

Normally e_2 will be quite small compared to e_1 since obviously the dip will never be as great as 90°. In practice we amplify e_2 about ten times as much as e_1 in order to obtain a record strip which can be more clearly read. The amplification is taken into account in computing the value of the tangents of the dip angle. This enables us to obtain more reliable measurements of e_2 and makes our readings more accurate.

Our method may be used in connection with core drilling or other shallow drilling or drilling conducted solely for explorative purposes to determine structure of the shallow beds in order to properly locate prospect holes. Our method may also be used in conjunction with other commonly employed well logging methods to supplement the information there gained.

It will be observed that we have accomplished the objects of our invention. We have provided a novel manner of obtaining the amount and direction of the dip of buried geological strata from which structure maps may be plotted. We are able to locate the portions of structures and are therefore able intelligently to locate wells.

It will be understood that certain features and sub-combinations are of utility and may be employed without reference to other features and sub-combinations. This is contemplated by and is within the scope of our claims. It is further obvious that various changes may be made in details within the scope of our claims without departing from the spirit of our invention. It is, therefore, to be understood that our invention is not to be limited to the specific details shown and described.

Having thus described our invention, we claim:

1. A method of logging bore holes to determine the dips of the strata pierced thereby, including the steps of passing a current through the geological section pierced by the bore hole, observing the potential difference between horizontally disposed electrodes positioned in a bore hole adjacent a stratum being investigated, simultaneously observing the potential difference between vertically spaced electrodes positioned within the bore hole adjacent the stratum being investigated, and ascertaining the dip of the stratum from said potential differences.

2. A method of logging bore holes including the steps of passing a current in a given direction through the geological section pierced by the bore hole being investigated, lowering horizontally and vertically spaced groups of electrodes into said bore hole, simultaneously moving a record strip as a function of the movement of said electrode groups, recording the potential difference between said horizontally spaced electrodes, simultaneously recording the potential difference between said vertically spaced electrodes and determining the dips of the various strata past which the electrodes are moved by the ratios of the horizontal and vertical potential differences.

3. A method of logging bore holes including the steps of passing a current in a given direction through the geological section pierced by the bore hole being investigated, lowering horizontally and vertically spaced groups of electrodes into said bore hole, simultaneously moving a record strip as a function of the movement

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of said electrode groups, recording the potential difference between said horizontally spaced electrodes, simultaneously recording the potential difference between said vertically spaced electrodes, determining respective components of the dips of the various strata past which the electrodes are moved by the ratios of the horizontal and vertical potential differences, then passing current through the geological section being investigated in a direction at an angle to said first direction, repeating the above steps to obtain another component of the dips of the geological strata past which the electrodes are moved, and obtaining the resultant of said dip components to ascertain the true dips of the strata through which the bore hole is sunk.

4. A method as in claim 1 in which the current is direct current.

5. A method as in claim 1 in which the current is alternating current.

6. A method as in claim 1 in which the current is alternating current of a predetermined frequency, including the steps of rejecting potential differences above said predetermined frequency, rejecting potential differences below said predetermined frequency, amplifying and observing potential differences of said predeter-

mined frequency and determining the desired dip from said amplified potential differences.

7. A method as in claim 1 in which said current passing step is conducted momentarily to obtain transient current.

8. A method of logging bore holes to determine the dips of the strata pierced thereby, including the steps of passing an electrical current through the geological section pierced by a bore hole, receiving the potential differences between a point and a plurality of surrounding points disposed in a plane adjacent a stratum being investigated, amplifying each of said potential differences between said central point and one of said surrounding points, rectifying the amplified potential differences, integrating the rectified amplified potential differences and observing the integrated potential difference, simultaneously observing the potential difference existing between a point above said plane and a point below said plane extending from said first point in a line at right angles to said plane, and ascertaining the tip of the stratum from said second potential difference and said integrated potential difference.

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